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Search for Evidence of Low Energy Protons in Solar Flares

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Hénoux *et al.* (*Ap. J. Supp.*, **73**, 303, 1990) recently obtained observations of linear polarization in the $H\alpha$ line during three solar flares, which they interpreted as impact polarization from a hecta-keV proton beam colliding with chromospheric hydrogen. They discuss several characteristics of impact polarization which allow its identification. First, for a vertical proton beam, the polarization should be directed towards the center of the solar disk and, second, the polarization should be strongest at the limb and weakest at disk center (for a truly vertical beam, the polarization would vanish at disk center). Hénoux *et al.* have identified the observed polarization as impact polarization based on its direction, which pointed along the line from the observation point to disk center in all three flares (to within ± 20 degrees).

We searched for linear polarization in the $H\alpha$ line using the Stokes Polarimeter at Mees Solar Observatory (Mickey, *Solar Phys.*, **97**, 223, 1985) and present observations of a flare from NOAA active region 6659 which began at 01:30 UT on June 14, 1991. The Stokes Polarimeter has significantly better sensitivity to the polarization than Hénoux's instrument, but it does not have as large a field-of-view. Our dataset also includes $H\alpha$ spectra from the Mees CCD (MCCD) imaging spectrograph (Penn *et al.*, *Solar Phys.*, in press, 1991), as well as hard X-ray observations from the BATSE instrument on board GRO (Fishman *et al.*, in *Proceedings of the Gamma Ray Observatory Science Workshop*, ed. W. N. Johnson, 1989). Hénoux *et al.* did not have $H\alpha$ spectra or hard X-ray observations.

The polarimeter scanned a $40''$ by $40''$ field-of-view using 16 raster points in a 4×4 grid. Each scan took about 30 seconds with 2 seconds at each raster point. The polarimeter stepped $8.5''$ between raster points and each point covered a $6''$ region. This sparse sampling increased the total field-of-view without reducing the temporal cadence. At each raster point, an $H\alpha$ spectrum with $20 \text{ m}\text{\AA}$ spectral sampling is obtained covering 2.6\AA centered on $H\alpha$ line center.

Figure 1 shows, as a function of time, the $H\alpha$ linear polarization averaged over a 0.4\AA band centered on the $H\alpha$ line. In this figure, the polarization is also averaged over all raster points in the $40''$ by $40''$ field-of-view. Since the direction of the polarization is an important diagnostic, we broke the polarization down into two components: one directed towards disk center (solid line) and one directed perpendicular to this (dotted line). The solid horizontal line is three times the standard deviation of the preflare polarization (01:15 - 01:30 UT) and indicates the significance of the observation. The figure ends at 01:40 UT since no data was obtained after that time. During the flare, the disk-center component of the polarization appears to increase preferentially as predicted by the impact polarization hypothesis.

In an alternative representation of the directionality of the polarization, **Figure 2** is a histogram of the polarization direction throughout the observations. The histogram

includes polarization at all wavelength points between $\pm 0.3\text{\AA}$ from line center and from all pixels and all times when the polarization was greater than 2.5%. The histogram bins are 9 degrees wide and the dashed line shows the direction of disk center. The polarization is directed roughly 20 degrees off of the disk center direction, a reasonable value considering the possible inclination of the chromospheric magnetic field.

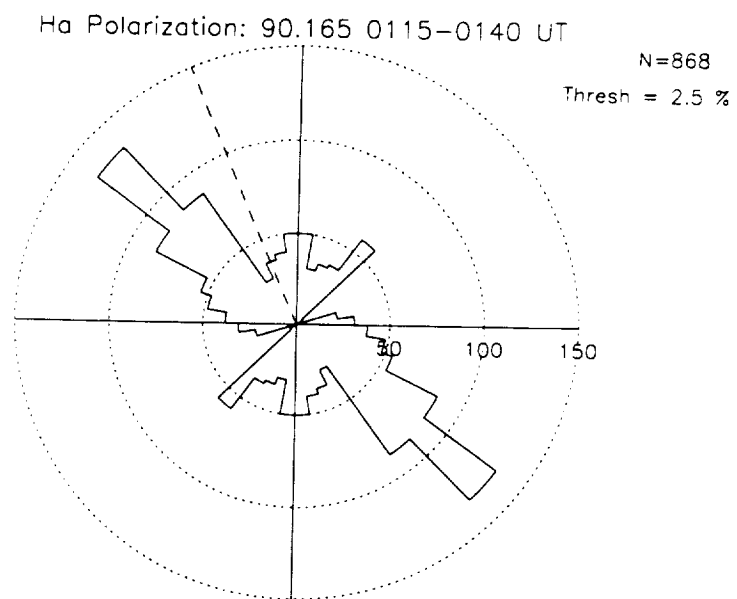
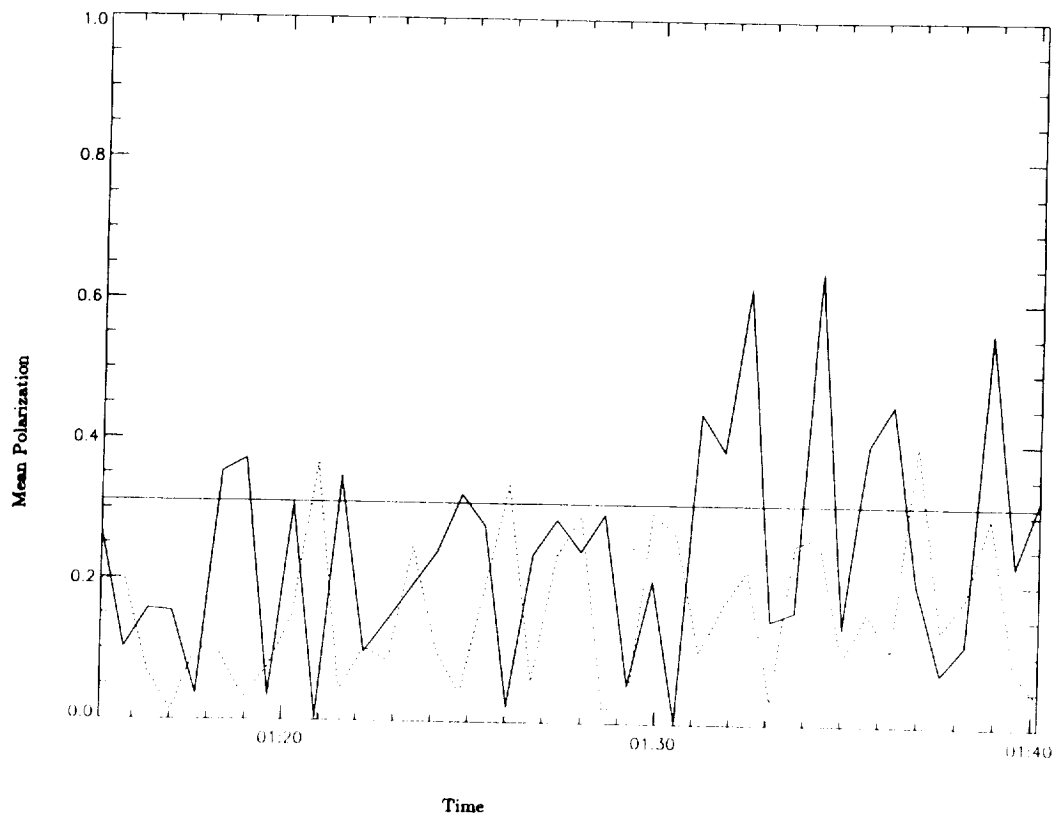
Figure 3 demonstrates the spatial relationship between the observed polarization and the $H\alpha$ flare. The underlying image from the MCCD imaging spectrograph shows the difference between the spectroheliogram (SHG) obtained 1.8\AA blueward of line center and the SHG obtained 3.6\AA blueward of line center at 01:32:54 UT. Since precipitating electrons give the $H\alpha$ profiles broad Stark wings, this image indicates sites of non-thermal electron precipitation. The white line segments show the direction and strength of the fractional $H\alpha$ linear polarization from the scan beginning at 01:32:28 UT; the polarization occurs near the region where electrons are precipitating. The co-alignment between the MCCD image and the polarization has an uncertainty of approximately one polarimeter raster point ($8''$).

Figure 4 displays the hard X-ray light curve observed by the BATSE LAD discriminators on GRO in the 25-50 keV channel. Comparing **Figure 4** with **Figure 1**, we see that four of the five most significant peaks in the $H\alpha$ polarization occurred over the same time interval as the peaks in the hard X-rays. This is consistent with a non-thermal origin of the $H\alpha$ polarization.

Figure 5 shows the soft X-ray light curve from the GOES satellite, and **Figure 6** shows the line center $H\alpha$ light curve integrated over the flare area as observed with the MCCD. Most of the $H\alpha$ emission and all of the GOES emission are thermal, and the linear $H\alpha$ polarization does *not* track these emissions, being impulsive in nature.

Preliminary Conclusions

- Significant linear $H\alpha$ polarization was observed during the June 14 flare and was preferentially directed about 20 degrees from disk center, consistent with nearly vertical particle precipitation.
- The $H\alpha$ polarization occurred near sites of non-thermal electron precipitation, as indicated by the Stark broadened $H\alpha$ wings observed with the MCCD, however, there was no compelling spatial relationship between these sites and the $H\alpha$ polarization.
- The $H\alpha$ polarization peaked at the times of the hard X-ray peaks, but did not track the soft X-ray or the $H\alpha$ light curves. This suggests that the linear polarization is caused by a non-thermal process.
- The angular, spatial and temporal character of the polarization is consistent with the predictions of impact polarization by approximately 100 keV protons.
- Assuming that the observed polarization is indeed the signature of 100 keV protons, these protons are temporally coincident with approximately 25-100 keV non-thermal electrons.



Figures 1 and 2

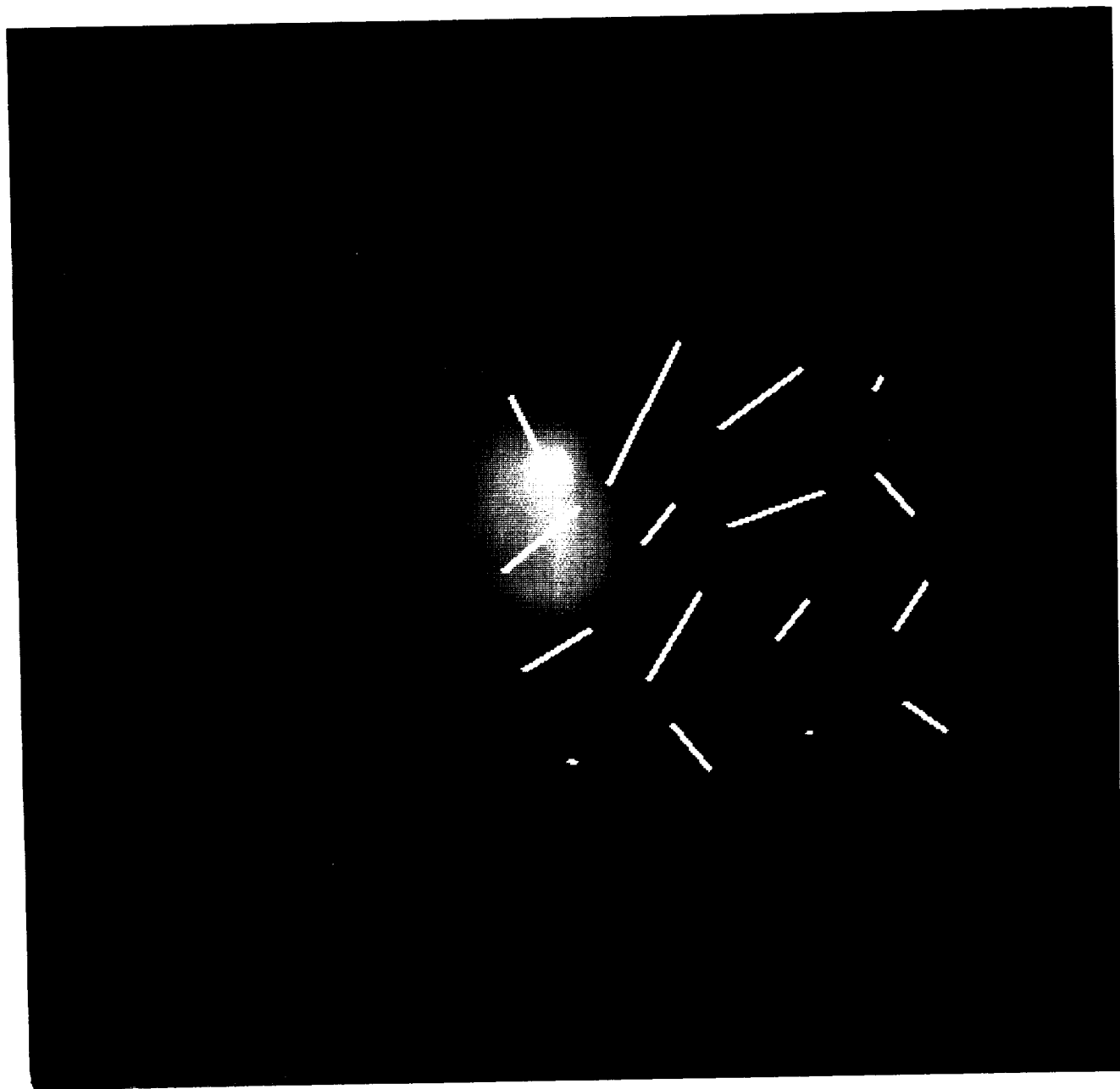


Figure 3

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BLACK AND WHITE PHOTOGRAPH

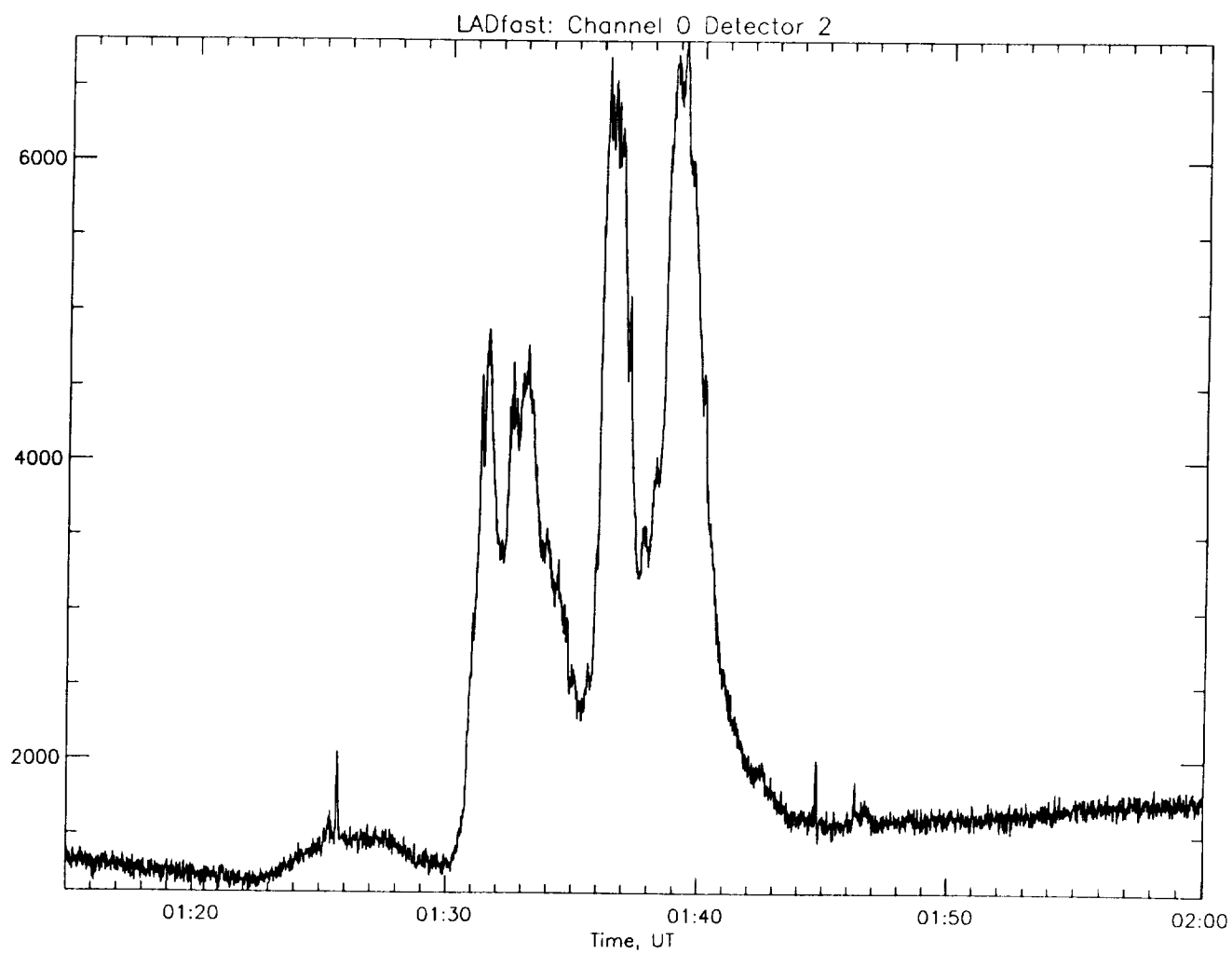
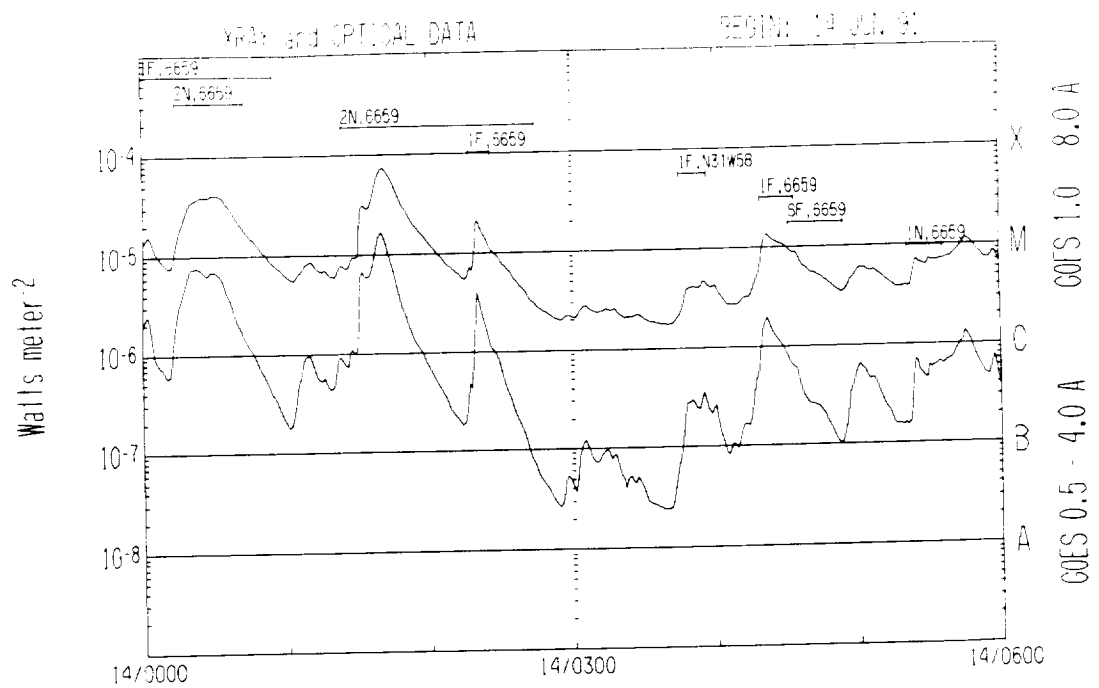
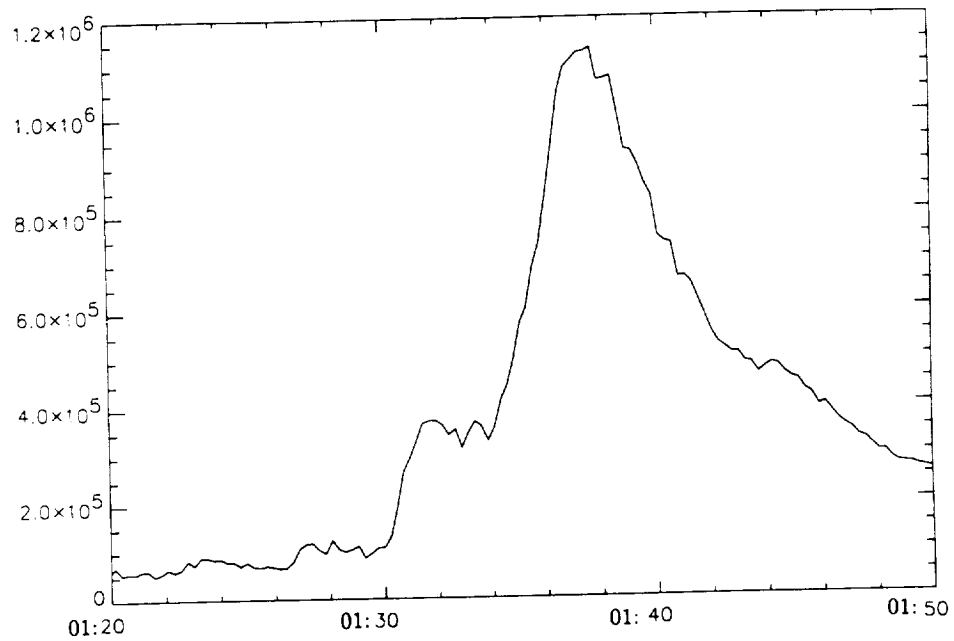


Figure 4

H α Power



Figures 5 and 6